ISSN 0020-4412, Instruments and Experimental Techniques, 2007, Vol. 50, No. 4, pp. 561–564. © Pleiades Publishing, Ltd., 2007.
Original Russian Text © K.K. Klimovskii, 2007, published in Pribory i Tekhnika Eksperimenta, 2007, No. 4, pp. 140–143.

A Testing Facility for Pumps Operating in a Supersonic Flow of a Water–Steam Mixture

K. K. Klimovskii

Baranov Central Institute of Aircraft Engine Construction, Aviamotornaya ul. 2, Moscow, 111116 Russia

Received December 22, 2006

Abstract—A testing facility designed for experimental studies and diagnostic tests of pumps in a supersonic flow of a water–steam mixture, which simulates natural working bodies in the boiling state, is described. The results of studies of pumps on the bench that have shown the possibility of changing to turboless system for supplying fuel into the engines of aircrafts.

PACS numbers: 47.85.Kn

DOI: 10.1134/S0020441207040264

Limited data on hydraulic testing facilities, which are designed mainly for diagnostic tests, are available in the literature, while the body of information on testing facilities for experimental studies is even smaller. However, in such branches of industry as aircraft and rocket building, in which it is constantly necessary to improve aircrafts and promising developing works are underway, the need of such benches for, e.g., studying the operation of pumps of fuel-supply systems is quite considerable. Therefore, it seems to be desirable to describe a universal hydraulic bench developed by the author and built at the Central Institute of Aircraft Engine Construction (CIAEC) under his methodological supervision for studying the pumps mentioned above.

In practice, during experimental studies of pumps, a natural working body for transferring of which the pump under study is designed is often replaced with a model working body (simulator) with limited or complete observation of the similarity criteria. One such study performed at the CIAEC was of an axial pump, which was designed with the use of an unconventional method, performed with a steam–water mixture (boiling water). The parameters of this mixture simulate the thermal properties of boiling hydrogen, which is used as a fuel component in power facilities of aircrafts.

When hydrogen or other fuel components are pumped over, the development of cavitation is allowed to a slight degree in order to avoid an abrupt degradation of the pump's energy parameters (initiation of cavitation) and catastrophic related consequences for aircraft. In order to avoid cavitation in a liquid flow entering a pump, a pressure is produced that is much higher than the saturation steam pressure P_s. For this purpose, an excess pressure is applied to the on-board fuel tanks. The higher this pressure, the more massive the tanks. Therefore, it is desirable to reduce the pressure in the tanks for the pumps to operate at a minimum possible inlet pressure that tends toward P_s as the limiting pressure, i.e., in a flow of a steam–liquid mixture that runs on a pump's blade rim at a supersonic velocity, because the speed of sound in such a mixture is three orders of magnitude lower than in pure water. To realize this idea based on the concept of supersonic flow, a pump has been developed that is capable of operating at an inlet pressure equal to P_s.

Figure 1 shows a structural diagram of the testing facility that has been developed for experimental studies of the working capacity of this pump. An original feature of this bench is that its elements are designed for executing a number of functions.

The bench contains closed hydraulic circuit *1* that contains high-speed axial pump *2*. The pump is rotated with electric motor *3* with a power of 1 MW through two-stage step-up gear *4* with replaceable gears that ensure gear ratios in the range 1–30. A steam generator in the form of two disks—stationary disk *5* and rotating disk *6*—is installed in front of pump *2*. These disks have a number of holes that are identical in shape, quantity, and size and coincide for both disks in the initial position of disk *6*. Figure 2 shows a schematic of the steam generator.

Cylindrical vessel *7* with ultrasonic level gage *8* is installed in the bench's inlet line (Fig. 1). In the upper part of vessel *7*, there is a valve, through which this vessel communicates with the atmosphere, and a nipple with faucet for pouring water into the line. A structural diagram of this vessel is shown in Fig. 3. The main function of vessel *7* (Fig. 1) is to measure the volume concentration of steam in front of pump *2*. In addition, it is used as an expansion tank that accumulates a surplus water volume, which forms during water heating, and simultaneously as a secondary degasifier. Throttle *9*, which is designed for high pressures (up to 300 bar) and intended for controlling the flow rate of the pumped

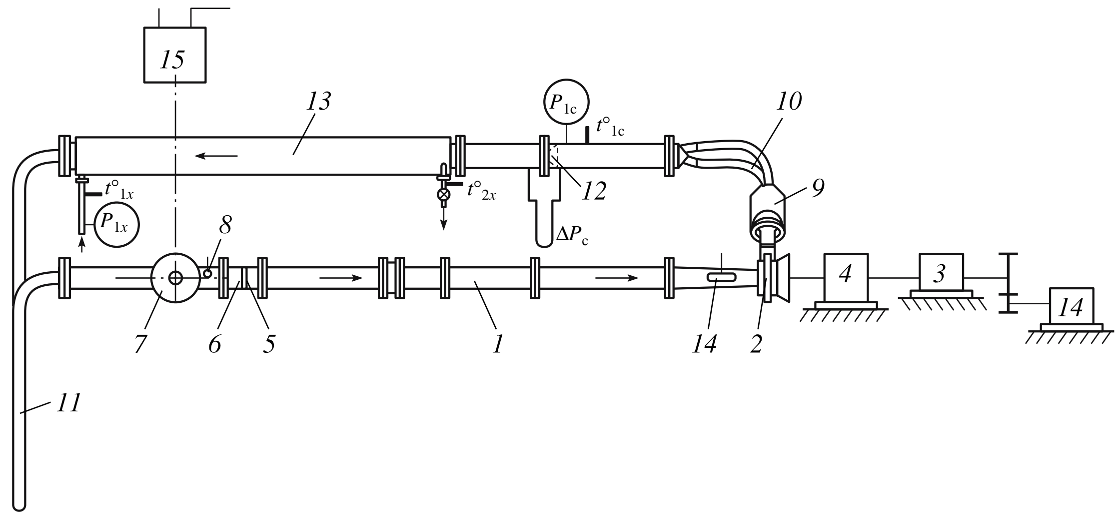

Fig. 1. Structural diagram of the testing facility with a closed hydraulic circuit: (*1*) hydraulic circuit, (*2*) axial pump, (*3*) electric motor, (*4*) step-up gear, (*5, 6*) stationary and rotating disks, (*7*) vessel of the steam-content gage, (*8*) ultrasonic level gage, (*9*) throttle, (*10*) flexible hose, (*11*) compensator, (*12*) nozzle flow meter, (*13*) refrigerator, (*14*) servomotor, and (*15*) degassing tank.

water, is installed directly behind pump *2*. A ball valve that hermetically shuts the flow cross section of throttle *9* is its working element (Fig. 4). Throttle *9* (Fig. 1) is connected to the outlet line via two flexible high-strength hoses *10* that allow pumps of different dimensions and configurations to be connected to circuit *1*.

The inlet and outlet lines are connected through electric heater–compensator *11*, which has the form of a half-loop connected to the electric supply line. It heats water while simultaneously compensating for the thermal deformation of the circuit. In the outlet line, there is nozzle flow meter *12*, behind which refrigerator *13* is placed, this latter serving to stabilize the thermal conditions of circuit *1*. The testing facility has three service systems: a servodrive, a vacuum system, and a degassing system. The servodrive is servomotor *14* for aircraft coupled through a gear to the shaft end of engine *3*. The degassing system is manufactured in the form of tank *15* connected to the vacuum system. The structural diagram of this tank is shown in Fig. 5. In the upper part of tank *15* (Fig. 1), there is a sprayer of the water supplied to the tank and then poured into circuit *1*. This sprayer serves to intensify the gas liberation from the water. Several layers of ceramic crumbs that are placed in the bottom part of the tank adsorb the liberated gas, which is subsequently withdrawn via evacuation. Circuit *1* is equipped with draining branch pipes for removing air from the circuit during the process of its being filled with water.

The experimental procedure on our facility consists of two, preparatory and working, stages.

The succession of operations included in the preparatory stage is as follows. Hydraulic circuit *1* is slowly

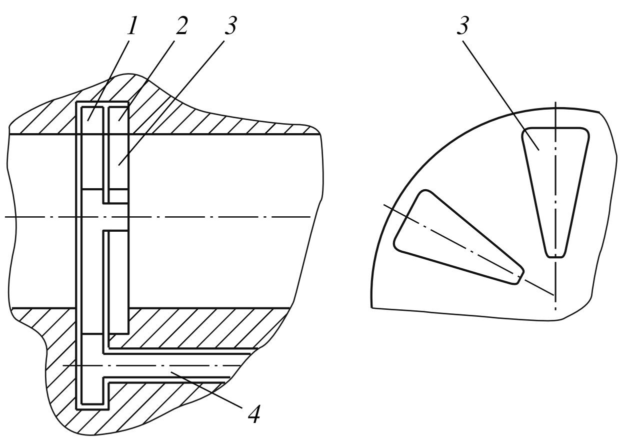

Fig. 2. Steam generator: (*1*) rotating disk, (*2*) stationary disk, (*3*) holes in disks, and (*4*) shaft of the rotating-disk drive.

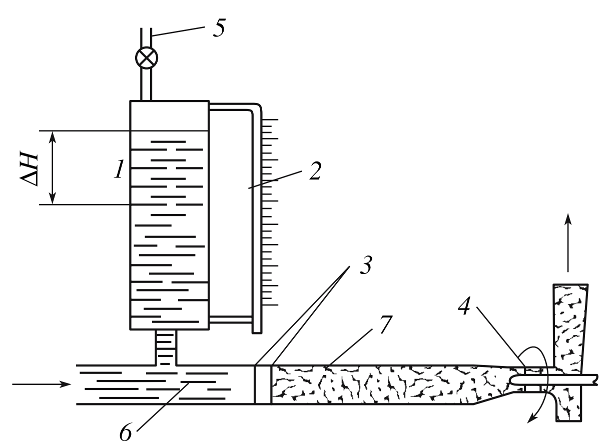

Fig. 3. Steam-content gage: (*1*) vessel, (*2*) level gage, (*3*) disk steam generator, (*4*) pump, (*5*) branch pipe for filling the vessel, (*6*) water, and (*7*) steam–water mixture.

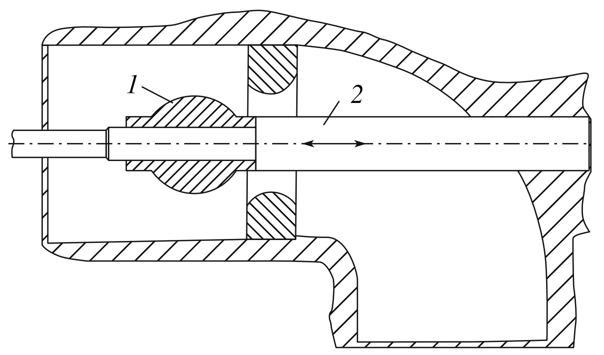

Fig. 4. Outlet throttle: (*1*) ball valve and (*2*) driving rod.

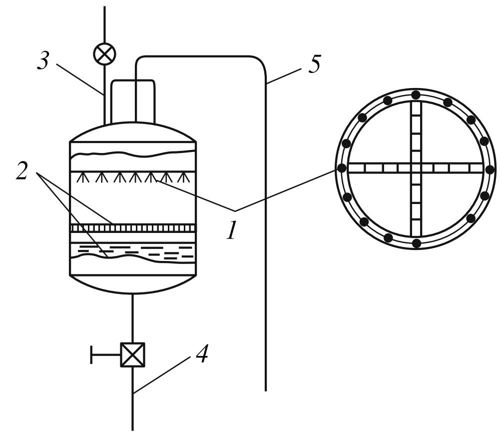

Fig. 5. Degassing tank: (*1*) sprayer, (*2*) ceramic-crumb layers, (*3*) vacuum system's branch pump, (*4*) pipe for pouring water into the circuit, and (*5*) line for supplying water into the tank.

filled with water from a water main through degassing tank *15*, from which water enters vessel *7*. The filling process occurs at the open valve in the upper part of the vessel and the open draining branch pipes for removing the air accumulated in the circuit. After the circuit is filled with water to the required level in the vessel, which is monitored with level gage *8*, the degassing tank is shut off and heater *11* is turned on. To ensure accelerated and uniform heating of the water, its circulation in circuit *1* is provided with the use of a servodrive. For this purpose, servomotor *14* is turned on and begins to rotate the shaft of motor *3*, step-up gear *4*, and pump *2* under study, which slowly pumps water throughout entire circuit *1*. Hence, the above elements form a circulator that, in addition to the main functions executed by each element, performs an auxiliary "self-service" function without using an external pumping substation. After water is heated to the boiling point (~100°C), vessel *7* and the draining branch pipes are sealed. Servomotor *14* is turned off, and main motor *3* is driven. Because circuit *1* is closed, the entire energy fed to the pump is converted into heat, water is rapidly heated to a specified temperature, and corresponding pressure P_s establishes in circuit *1*. Heater *11* is turned off in order to avoid overheating, and temperature stability is ensured by controlled operation of refrigerator *13*.

After the thermal conditions in circuit *1* were stabilized, motor *3* was turned off and the water level in vessel *7* was measured with the use of level gage *8*. This was the last operation of the preparatory stage. The second stage—i.e., the experimental study of the pump operation—involved the following system of measurements. In each of the cross sections of the inlet to the blade rim of pump *2* and of the pump outlet, three holes were drilled along the circumference at an angle of 120° for measuring static pressures. Sets of total-pressure-measuring tubes were installed in the same cross sections. The water flow rate was measured with a standard nozzle manufactured and mounted according to GOST (State Standard) rules. For this purpose, holes were made in front of and behind nozzle *12* for measuring both the static pressure in front of it and pressure difference ΔP_{noz} across it (see Fig. 1). In addition, a thermocouple that measured temperature T_{noz} was mounted in front of the nozzle. The static pressures were measured in front of and behind the steam generator, and the corresponding holes were drilled as well.

To perform accurate temperature measurements of the steam–water mixture, so-called P_s gage *16* was mounted in front of pump *2* behind the steam generator. This device is a thin-walled vessel of streamlined shape made from a material with a high thermal conductivity and having a branch tube for measuring the pressure inside the cavity of the P_s gage. Before operation, vessel *16* half-filled with water is installed in circuit *1* and connected to the measuring device (manometer). Afterward, the remaining cavity in vessel *16* is evacuated together with the branch tube. When the mixture flows around this vessel, the water inside it is heated to the mixture temperature and pressure P_s produced in this water becomes equal to the pressure in the mixture. Measured pressure P_s in the vessel allows determination of the water temperature using the known dependence $P_s(T)$ for water.

To measure volume steam content φ, it is necessary to determine the water level in vessel *7* with level gage *8* after the water is heated to a preset temperature and motor *3* is stopped for a short time before the second (working) start. This level is formed as a result of thermal water expansion and corresponds to zero steam content. When the amount of steam produced by the steam generator in front of operating pump *2* increases, the forming steam displaces water into vessel *7*. When motor *3* is stopped after the preparatory stage, the increase in the water level in this vessel, V_v, relative to a fixed value corresponds to the steam volume in front of pump *2*. Because volume V of the line's segment from the steam generator to the pump's blade rim is known, desired value φ is determined easily as $\varphi = V_v/V$. To measure the torsional moment at the shaft of pump

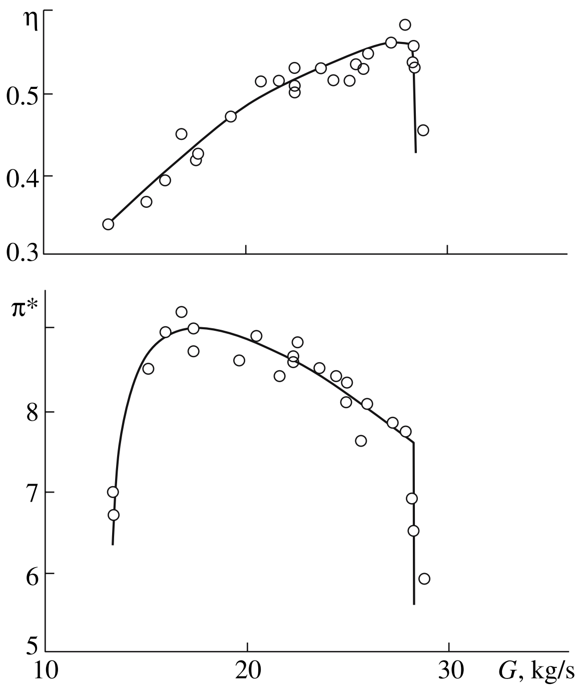

Fig. 6. Energy characteristics of the pump at a flow-stagnation temperature of $T^* = 453$ K and a volume steam content of $\varphi \approx 0.8$.

2 (the pump-consumed power), step-up gear *4* with a case rocking around the pole of engagement of the last pair of gears was used. The readings of the step-up gear were recorded with the registering device.

The procedure used to measure the characteristics of the pump is as follows:

(i) a preset rotation frequency of the pump is attained;

(ii) a preset temperature of the steam–liquid mixture is measured with P_s gage *16* and stabilized with the use of refrigerator *13*;

(iii) outlet throttle *9* is fully opened and a maximum flow rate is set;

(iv) displacement of disk *6* relative to disk *5* of the steam generator is used to generate a certain amount of steam in front of the pump;

(v) the pressure, the temperature, the mixture flow rate, the torsional moment, and the water-level increment in vessel *7* are measured according to the preparation scheme;

(vi) the position of throttle *9* is changed, and operations (iv) and (v) are repeated at each position;

(vii) a change to a new temperature is performed, and operations (ii)–(vi) are repeated; and

(viii) the following characteristic quantities are calculated from the measured values of parameters—mixture flow rate G, degree of increase π^* of the total pressure in pump *2*, and its efficiency η—and the pump's characteristics, one of which is shown in Fig. 6, are plotted; it is of importance that this and some other characteristics have been obtained on the created testing facility at a volume steam content at the pump inlet of $\varphi \approx 0.8$. This means that the tested pump can operate without a purposefully produced inlet pressure.

The developed multifunctional testing facility allows experimental studies and diagnostics of pumps operating in a supersonic flow of a steam–water mixture, which simulates thermal properties of natural working bodies in wide temperature (273–473 K) and pressure P_s (1–16 bar) ranges, as well as when a pump's rotation frequency increases to 50000 rpm.

The results of studying pumps on this testing facility make it possible to change to a turboless fuel-supplying system for aircraft engines.